SALMON RECOVERY SCIENCE REVIEW PANEL

Report for the meeting held

July 21-23, 2003

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, WA

This introductory material (pp. i-iii) is available on the RSRP web site, but as an aid to the reader we are now including it with individual reports.

Robert T. Paine	**University of Washington, chair**
Frances C. James	**Florida State University**
Russell Lande	**University of California – San Diego**
Simon Levin	**Princeton University**
William Murdoch	**University of California – Santa Barbara**
Ransom A. Myers	**Dalhousie University**
Beth Sanderson	**NOAA Fisheries liaison, RSRP report coordinator**

Recovery Science Review Panel

The Recovery Science Review Panel (RSRP) was convened by NOAA Fisheries to guide the scientific and technical aspects of recovery planning for listed salmon and steelhead species throughout the West Coast. The panel consists of six highly qualified and independent scientists who perform the following functions:

1. Review core principles and elements of the recovery planning process being developed by NOAA Fisheries.
2. Ensure that well accepted and consistent ecological and evolutionary principles form the basis for all recovery efforts.

3. Review processes and products of all Technical Recovery Teams for scientific credibility and to ensure consistent application of core principles across ESUs and recovery domains.
4. Oversee peer review for all recovery plans and appropriate substantial intermediate products.

The panel meets 3 to 4 times annually, submitting a written review of issues and documents discussed following each meeting.

Expertise of Panel Members

Panel members have all been involved in local, national, and international activities. They have served on numerous National Research Council committees and have published many papers in prestigious scientific journals.

Dr. Robert T. Paine (chair), University of Washington

- *Field of expertise*: Marine community ecology, complex ecological interactions, natural history
- *Awards*: National Academy of Sciences member; Robert H. MacArthur award recipient from the Ecological Society of America; Tansley Award from the British Ecological Society; Sewall Wright Award from the American Society of Naturalists; Eminent Ecologist Award from the Ecological Society of America
- *Scientific leadership*: Member of multiple National Research Council committees, editorial boards, past president of Ecological Society of America
- *Research*: About 100 scientific publications

Dr. Frances C. James, Florida State University

- *Field of expertise*: Conservation biology, population ecology, systematics, ornithology
- *Awards*: Eminent Ecologist Award from the Ecological Society of America; leadership and dedicated service awards from the American Institute of Biological Sciences
- *Scientific leadership*: Participant on National Research Council panels; service on many editorial boards; Board of Governors for The Nature Conservancy; past president of the American Institute of Biological Sciences; scientific advisor for national, state, and local activities
- *Research*: More than 105 scientific articles published

Dr. Russell Lande, University of California-San Diego

- *Field of expertise*: Evolution and population genetics, management and preservation of endangered species, conservation and theoretical ecology
- *Awards*: Sewall Wright Award from the American Society of Naturalists; Guggenheim Foundation; MacArthur Foundation; Fellow of the American Academy of Arts and Sciences
- *Scientific Leadership*: Past President of the Society for the Study of Evolution; International recognition; developed scientific criteria for classifying endangered species adopted by the International Union for Conservation of Nature and Natural Resources (IUCN)
- *Research*: More than 125 scientific publications

Dr. Simon Levin, Princeton University

- *Field of expertise*: Theoretical and mathematical ecology, evolutionary ecology, complex ecological systems

- *Awards*: National Academy of Sciences member; Robert H. MacArthur award recipient from the Ecological Society of America; Statistical Ecologist Award from the International Association for Ecology; Distinguished Service Award from the Ecological Society of America; Guggenheim Fellowship; Fellow, American Academy of Arts and Sciences; Fellow, American Philosophical Society; Okubo Prize, Society for Mathematical Biology and Japanese Society for Theoretical Biology
- *Scientific leadership*: Member of many National Research Council committees; Science Board, Santa Fe Institute; Committee of Concerned Scientists; Past President, Ecological Society of America; Society for Mathematical Biology; Technical Advisory Council, BP-Amoco
- *Research*: More than 300 technical publications

Dr. William Murdoch, University of California Santa Barbara

- *Field of expertise*: Theoretical and experimental ecology, population ecology
- *Awards*: Robert H. MacArthur award recipient from the Ecological Society of America; President's Award from the American Society of Naturalists; Guggenheim Fellowship; elected American Academy of Arts and Sciences
- *Scientific leadership*: Founder of National Center for Ecological Analysis and Synthesis; Director of Coastal California Commission 10-year study; scientific advisory panel member for the Habitat Conservation Plan for the California marbled murrelet
- *Research*: More than 125 scientific publications

Dr. Ransom A. Myers, Dalhousie University

- *Field of expertise*: Ecology, Conservation, and Management of Marine Animals, Modeling and Statistical Ecology, Population dynamics
- *Awards*: The Great Auk Lectureship (1999), Awarded first Killam Chair in Ocean Studies, Dalhousie University (1996)
- *Scientific leadership:* Member of Science Advisory Boards for Sierra Club of Canada (2003), Oceana (2003), and Atlantic Policy Congress (2000), Member of Board of Directors: The International Oceans Institute of Canada (2000) and Natural Resource Modelling Association (1994-1999). Asked to testify at the U.S. Senate Commerce Committee Hearing on Overfishing (2003) and the House of Commons (Canada) Standing Committee on Fisheries and Oceans (2003)
- *Research*: More than 110 scientific publications.

Dr. Beth Sanderson

- NOAA Fisheries liaison to the Recovery Science Review Panel
- Recovery Science Review Panel report coordinator

RECOVERY SCIENCE REVIEW PANEL (RSRP)

Northwest Fisheries Science Center, Seattle, Washington

July 21–23, 2003

1. OVERVIEW

A full committee (James, Lande, Levin, Myers, Murdoch, and Paine) met at the Northwest Fisheries Science Center on 21–23 July 2003. Our agenda is appended (Appendix A). Our primary focus was on the effects of hatcheries on wild salmon populations and their potential role in salmon recovery. We discussed how modification or closure of hatcheries provides NOAA Fisheries with opportunities to investigate the experimental effects of hatcheries on wild populations. We review some former and on-going stock manipulations, including telling results from a 9-year long Norwegian Cod study. For salmon, we identify key design issues and urge that NOAA Fisheries take the lead in multi-agency efforts to utilize planned hatchery closures and modifications as experimental units. Such actions should provide information vital to the recovery of endangered stocks.

2. HATCHERY EXPERIMENTS AND MONITORING

Introduction

Hatcheries are estimated to produce 80% of the fish in several key salmon fisheries. There are currently about 100 hatcheries in the Puget Sound and coastal Washington and about 200 in the Columbia Basin. Most are production hatcheries intended to boost the supply of salmon for commercial and recreational harvest. Conservation hatcheries (supplementation programs) have both production and conservation objectives. They attempt to lessen the genetic and ecological impacts of hatchery releases on wild fish by producing hatchery fish that are fully able to reproduce in the wild. The techniques used in supplementation programs include minimizing genetic divergence from wild fish, maintaining low rearing densities, providing antipredator conditioning, maintaining appropriate seasonal timing of maturation, and controlling the size at emigration to be similar to that of naturally spawning fish.

Reviews of hatchery programs charge that, until now, hatchery programs have lacked accountability and evaluation (Hilborn and Winton 1993, Lichatowich 1999). The Independent Scientific Advisory Board's (ISAB) recent review of salmon and steelhead supplementation programs in the Columbia River Basin questions whether supplementation programs are effective in improving the viability of wild stocks (ISAB 2003). The report charges that such programs require taking wild fish as broodstock, they risk domestication effects and potential genetic anomalies, they risk increased competition with natural-origin fish, and they may increase predation on natural-origin fish. The primary recommendation of this excellent report is that these issues be evaluated by manipulating hatchery programs in an experimental framework. The framework would compare hatchery populations to unsupplemented control populations and use target population abundances and fitness as response variables. To discover whether supplementation programs are having their desired effects, they must be compared with reference streams and coordination among projects needs to be improved.

At present, the reproductive performance of hatchery-origin adults, or even the consequences of widespread straying of conventional production hatchery fish, is not completely known. We do know that there is a negative impact of hatchery programs on threatened salmon (Levin et al. 2001, Chilcote 2003, and Nickelson 2003), but the direct and indirect mechanisms by which hatchery programs are affecting endangered salmon are largely unknown. The RSRP agrees with the conclusions of the ISAB (2003) report and argues for an even more comprehensive experimental program than that report proposes.

Some earlier studies discussing hatchery-based issues are identified in Appendix B. We include this list of studies to emphasize an unfortunate duality: questions on the negative impact of hatchery fish on wild stocks abound (so the RSRP's interest is hardly novel), while scant progress has been made toward investigation and resolution of this major topic.

Experimental Approaches to the Recovery of Endangered Salmon and the Role of Hatcheries

Active Adaptive Management

Clearly, salmon scientists and managers in the Pacific Northwest should structure their actions so that the results will lead to new information that can be used to guide future actions. The efficacy of recovery actions will be affected by local and regional environmental and habitat features; temporal changes in the environment; genetic adaptations; local and regional human factors like habitat degradation, harvest, hydropower, and hatcheries (the "4Hs"); and other factors. Hatcheries are only one of these factors. Because there are so many simultaneous processes affecting salmon, there needs to be a concerted effort to design studies that attempt to sort out the relative importance of possible limiting factors. The only way to accomplish this goal is to define objectives carefully and to set up comparisons that allow experimental design principles to be incorporated into research and management actions.

Some of this work will require a new level of spatial integration. Key criteria for spatial integration were discussed in the RSRP's December 2002 report (Appendix C). The December 2002 report should also be consulted on the need to evaluate, in a comprehensive way, recovery actions that may be taken in different parts of the salmon freshwater habitat—from high creeks to estuaries—but that nevertheless affect the productivity of a single wild salmon population. Such integrated analysis will be the only way to obtain information on the scale of the question of the relative effects of the different human impacts on salmon.

The term adaptive management is used so variously that it is losing its meaning (Ludwig et al. 2001). Experimentation is already being implemented in parts of the Columbia Basin under the name of "adaptive management" (Lee 1989), although not at the scale proposed in this report. Adaptive management is also advocated by the Hatchery Scientific Review Group for

Puget Sound and coastal Washington, but the meaning there emphasizes monitoring and evaluation rather than experimentation. To assure that we differentiate what the RSRP proposes from a more general policy of learning by experience, we use the term "active adaptive management" proposed by Walters and Hilborn (1976, 1978), Walters (1986), and Walters and Holling (1990). Active adaptive management involves a two-step process: first, a concerted effort to integrate interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies; second, large-scale long-term management experiments designed to fill important information gaps needed to differentiate among the alternative management options. In several past cases, the modeling step clarified the specific goals and the likelihood of various processes, but practical impediments prevented the implementation of the second step, the long-term experiments (Walters 1997). Now the excellent major recent review of hatchery programs in the Columbia Basin (ISAB 2003) recommends new standards of accountability for hatcheries, coordination of hatchery programs within regions, general decreases in hatchery production, and basinwide experimentation, all laudable steps. There is even the beginning of a coordinated program for the Columbia River Basin (IHOT 1995) led by an interagency team that recommends eliminating hatcheries where the prognosis for freshwater habitat rehabilitation is high. Thus, the possibility of designing a large-scale experimental program for the Columbia Basin is improving. If that is to be accomplished, the complex institutional setting in which salmon management is embedded there and elsewhere will require a new level of interagency leadership and cooperation.

The program we would like to see would have a long-term, comprehensive, basinwide experimental design and a larger proportion of marked fish than presently occurs. Some possible consequences of the current programs that could be tested with large-scale experimentation involving hatcheries follow. We note that none of these issues is trivial and that their resolution could contribute substantially to recovery goals for listed ESUs.

- Do hatchery releases cause extreme ecological stress to natural fish in streams?
- Will supplementation hatchery programs increase the number of natural-origin adults on the spawning grounds?
- Are there only minor negative consequences of taking wild fish for broodstock?
- Is the increased predation on natural-origin fish in a mixed-species fishery significant?
- Do hatchery releases seriously influence the marine growth and survival of natural fish?
- What is the effect of spawners that are strays from production hatcheries on the genetics of wild stock?

Examples of Previous Experiments and Proposals for Future Experiments

Some outstanding examples of past experiments illustrate how efficiently an experimental approach can clarify ecological processes operating in nature. From 1925 to 1936, Foerster (1936, 1938) tested the relative efficiency of natural and artificial propagation of sockeye salmon in Cultus Lake, British Columbia, contributing to the population in the lake. During the population's 1-year residence in the lake, artificial propagation provided no advantage over natural spawning in maintaining the run. Based on this result, British Columbia closed its hatcheries from 1940 to1980 (Lichatowich 1999). From 1980 to 1985, Nickelson et al. (1986) compared the effects of stocking hatchery coho presmolts with no stocking in 30 Oregon coastal streams. In the 15 stocked streams, the hatchery presmolts displaced the smaller wild juveniles; then the hatchery-reared adults spawned too early, so the stocking failed to rebuild the wild population.

Reisenbichler (in press) has proposed a series of smaller-scale genetic experiments that could identify domestication problems with hatchery fish. For example, he proposed common-garden experiments in semi-natural environments. There have also been some recent attempts at watershed-scale hatchery experiments. One example is the Idaho Supplementation Studies summarized in the ISAB report (ISAB 2003). Another involves the Hood Canal summer chum supplementation programs, in which unsupplemented control streams were explicitly identified and monitored (see http://www.wa.gov/wdfw/fish/chum/chum.htm). Finally, a supplementation study of Hamma Hamma steelhead involves use of an unsupplemented control stream (B. Berejikian[1]). All the above represent recent attempts by NMFS and other groups to study the effects of hatcheries in an experimental setting. In all examples that the RSRP has been able to locate, when experiments were conducted to test claims for the success of hatcheries in promoting the conservation of naturally spawning fish, the initial claims have been proven false. There is an obvious need for additional experiments testing the efficacy of conservation hatcheries and of modified systems that have the joint objective of production and conservation.

The Scale Needed for Hatchery Experiments: Learning from the Experience of Cod in Norway

There is much to be learned from experience with other species; therefore, we include a brief description of the history of cod hatcheries in Norway. Cod hatcheries at the turn of the last century in the North Atlantic were in a situation similar to that of salmon hatcheries in the Pacific Northwest today; there were many hatcheries, with strong proponents and equally strong critics.

In 1864, G. O. Sars proposed that exploited cod populations could be increased by the use of hatcheries to produce larvae or codlings. Large-scale hatcheries of cod were constructed in southern Norway in 1882 (Dahl 1906) and were claimed to be a great success. It was possible to interpret the hatcheries as being very successful; this was claimed for at least 81 years (Dannevig 1963). However, the outplanting of the larvae was such that the results could be interpreted as an experiment, and were analyzed using analysis of variance. The results were simple and unambiguous: the cod hatcheries were not effective (Tveite1971). The key design of these definitive experiments was simple: randomization (a random assignment of fiords to receive hatchery supplementation), replication (many years and fiords were used), and standard monitoring (the results were monitored using beach seines the following year).

---

[1] Barry Berejikian, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097.

In the 1980s technology had improved, and it was believed that the release of 1-year-old cod could effectively increase cod production. This time, carefully designed large-scale experiments were undertaken (Ultang 1984 before commercial operation began. The results were published in the peer reviewed literature (over 35 papers from the experiment are reviewed by Smedstad et al. 1994). It was found that stocking of 1-year-old codlings produced no difference in abundance at age 2; food resources were fully exploited by wild fish and further supplementation did not improve production because of strong density-dependent mortality.

Hatcheries for the production of 1-year-old cod have never left the experimental stage in Norway. Thus, these large-scale experiments, on the scale of fiords, kept the Norwegian government from squandering millions of dollars on cod hatcheries (Salvanes 2001). The Norwegian experiments should be studied closely as an example of where careful, large-scale (on the scale of fiords), and long-term (9 years) experiments produced profoundly useful results for managers.

Comments on an Experiment "Estimating Selection Gradients in a Salmon Population Using Molecular Markers"

Ford et al. (unpublished ms.) have begun to carry out a clever experiment to measure ongoing natural selection and current relative fitness of hatchery and wild coho salmon in Minter Creek in Puget Sound. The researchers sampled nearly all adult fish returning to Minter Creek by capturing them at the weir and identifying them as being of wild or hatchery origin (from fin clips and scale rings), simultaneously obtaining a tissue sample for genotyping and assigning returning offspring to the sampled parents. The existence of the weir allows them to regulate the proportion of wild and hatchery fish allowed to spawn in the wild (except for uncontrolled escapees or inefficiency of the weir) without shutting down the hatchery or even the coho program at Minter Creek Hatchery. Initial results found no significant differences in relative fitness between hatchery- and natural-origin fish, a finding that is consistent with the long-term genetic mixing between the two groups. In the generation analyzed thus far, researchers allowed about equal numbers of hatchery- and wild-origin fish to pass the weir. In the future, according to Ford, they plan to reduce and eventually eliminate hatchery fish from spawning above the weir.

The RSRP wishes to emphasize that critical data on the demographic and genetic effects of hatchery fish on the wild population can be obtained only by completely eliminating gene flow from the hatchery to the wild population, and by observing demographic and evolutionary changes in both populations as they (re)adapt to their own environments. Ford et al. (unpublished ms.) estimate selection gradients on several characters separately in males and females, but pool hatchery and wild fish together. This procedure is questionable, because it does not allow detection of differences in environmental effects or fitness due to the hatchery versus the wild environments. In the future, when gene flow between the two is eliminated, it will be essential to measure fitness and natural selection separately in the wild and hatchery populations over several generations.

A full assessment of interacting demographic and genetic effects of hatchery fish on the wild population can only be obtained from additional experiments in which some hatchery programs (if not the entire hatchery) are completely terminated to remove competition between hatchery and wild fish in freshwater and estuarine habitats, a recommendation that Ford has supported in agreement with the RSRP.

Other Questions about Potential Negative Effects

Some questions about the potential for negative genetic effects of hatchery fish on naturally produced fish that also necessitate experimentation may not require that they be on the scale of active adaptive management. For example, how important are domestication effects, or inbreeding or outbreeding depression of fish with one or two hatchery-origin parents?

Hatchery Experiments

In the near future, it is likely that many production hatcheries will be closed, and the operation of others will be modified. Such actions should be planned and evaluated, to the extent possible with hatchery administrators, scientists, and statisticians as participants in the context of an overall spatially extended experimental design. In this section, the RSRP discusses hatchery closure only, but intends these comments to refer to all recovery-targeted changes in hatchery operation, including pulsing hatchery production to allow estimates of the magnitude of their effects on the ecological interactions between hatchery fish and wild fish and the closure of weirs that control entry of hatchery salmon into a watershed.

The RSRP's aim is to provide one possible general conceptual framework for carrying out hatchery modifications in an integrated program. We will not discuss the myriad statistical decisions and details that will arise in implementing such a program and analyzing its results. As with several other aspects of potential salmon recovery actions, we advocate a combination of modeling and experimentation at the watershed level, designed to sort out the relative impacts of various potential recovery actions.

The Goal—Estimating Effects

The aim is not simply to test the hypothesis that hatchery production affects wild salmon populations—it does. The intent is to estimate the extent to which the addition of hatchery-reared salmon to a river affects wild salmon. Specifically, the aim is to estimate the effects of

1. production from a single hatchery, or
2. production from hatcheries in general, or
3. production by hatcheries of a given type in a given region, on (a) one native salmon population or (b) all populations in a region, or (c) populations of a given salmon type.

The above numbered questions define a central problem underlying any likely experimental design. Each production hatchery is unique. Its effects are determined by its own characteristics and those of the affected salmon in their unique environment. But is there sufficient commonality of effects that hatcheries across the Northwest are effectively replicates? Are the effects of hatcheries in Puget Sound similar enough that they can be regarded as replicates, but not as replicates of those in coastal Oregon? The experimental design should attempt to answer these questions.

Key Design Issues

Local design—BACIP. One possible basic *local* design that can be replicated on a broad scale is to stop (or otherwise modify) hatchery production and to compare various aspects of subsequent performance of the affected wild salmon population with those in a population whose hatchery operation(s) has (have) not been altered. BACIP stands for Before-After-Control-Impact, Paired (Stewart-Oaten et al. 1986, Stewart-Oaten and Bence 2001). In this case, a modification of the original BACIP design, the control population retains its unaltered hatchery or hatcheries; the "paired" impact is the "treatment" population whose hatchery production has been stopped or altered; and control and impact populations are paired in the sense discussed below.

Measurements are taken in both populations before the treatment is imposed. Such "before" measurements should be made whenever possible, because such data greatly strengthen inferences that can be drawn. A single observation is the *difference*, measured at some point in time, between the treatment and control populations. The *average* difference, over time, is estimated for the before period. The difference is then measured at a sequence of times after the treatment is imposed, and again the *average* difference in the after period is estimated. We then ask: how did the treatment affect the *average difference* between the two populations? For example, we might find that before the treatment the control population, on average, had a native salmon density twice that of the treatment population; whereas in the after period, that difference increased, on average, to eightfold. (The RSRP report of March 13–14, 2001, pages 9 and 10, describes a range of genetic, phenotypic, demographic, and population features that might be measured.)

The experimental unit. Although hatchery production will be manipulated, the experimental unit is the stream, and the response variable is a characteristic of the wild salmon population. Treatments (hatchery production changed) are randomly assigned to streams with hatcheries. Replicates are repeated cases of pairs of streams that are treated and not treated. Consideration will need to be given to the comparability of the salmon populations and the number and similarity of hatcheries that affect each population, as discussed next.

Pairing populations. An important and useful feature of the BACIP design is that treatment and control populations do not need to be ecologically "the same." *They simply need to track changes in their shared environment (e.g., in weather and climate) in the same way*. Pairs of populations are selected that seem similar in major respects, but they do not need to be identical in all respects; they just need to respond similarly to much of the temporal environmental variation, especially to variation with effects lasting more than one year.

Experimental blocks. This aspect of the design should respond to the three numbered questions above. One possibility is to regard different regions, and salmon species within regions, as blocks.

As noted above, we might expect *a priori* that the effect of production hatcheries is substantially different in Puget Sound and coastal Oregon. We would not, therefore, pair two hatcheries chosen from these two regions. We will want to know, however, if hatcheries in the two regions indeed have different effects. We may find that the effects have the same sign (e.g., wild salmon abundance increases after hatchery removal in both areas) and differ only in the magnitude of their effect. Thus, by treating the regions as "blocks," we can detect regional differences but may also be able to combine results from different regions to estimate more effectively generic effects of hatcheries. As always, there will be a trade-off between replication within blocks and the number of blocks examined.

Timing of treatments. In each block, we would have a collection of pairs of salmon populations, the members of each chosen to be as similar as possible. The treatment (i.e., hatchery removed) and control (hatchery unaltered) hatcheries' populations would be designated at random from each pair. In an ideal world, this choice would be made at a single time across all populations and all blocks (unless we wanted to know how hatchery effects change over different time periods). Differences between each control-treatment pair would then be measured for up to 10 years before the treatment is to be imposed; the treatment would then be imposed simultaneously across all experimental units.

The real world will not match this ideal. Closures are likely to be made at different times in different places. However, the long-term effect of the treatment (i.e., the estimated change in average difference between treatment and control) may well not depend on when the treatment is applied.

Recommendations

Because of the desirability of obtaining "Before" data, we recommend that TRTs in each region seek likely treatment and control pairs of salmon populations and begin a program of monitoring key variables as soon as possible. Even if some pairings ultimately receive no treatment, the extent to which different salmon populations track environmental variation in parallel will be useful in interpreting future data. Further, we recommend that one criterion for choosing (some or most) experimental and control sites should be the existence of at least several years of past demographic data, and that if such data exist, then it should take at most one or a few years to gather phenotypic and genetic data before experiments begin. In addition, we cannot emphasize enough the importance of monitoring the performance of natural and hatchery fish in the short and long run. Such actions take advantage of the existing spatial and temporal differences among populations in their relative degree of hatchery influence.

Some recent regression analyses have investigated the relationship between hatchery releases, or the proportion of hatchery spawners in a population, and natural population productivity (e.g., Chilcote 2003; Nickelson 2003). These types of analyses would have been even more informative if more populations had been monitored in a consistent way. Additional regression and path analytic analyses could probably help researchers and managers design specific manipulative experiments. Eberhardt and Thomas (1991) provide a useful broad-ranging review of the designs of sampling studies and the relative power of the inferences that can be derived from them.

Our overall recommendation is that NMFS should take the lead in organizing an effort by scientists, authors of recent hatchery review teams, administrators of hatcheries, managers, and statisticians to apply active adaptive management at the watershed level, as advocated by Carl Walters and Ray Hilborn (Walters and Hilborn 1976 and 1978), to the problem of the recovery of endangered populations of natural salmon in the Pacific Northwest and California. If the program can simultaneously address potential threats other than hatchery influences, all the better. Our comments above are simply suggestions for how to get started. We know that we don't understand all the complexities and difficulties that will be involved. However, we are convinced that some agreement on specific goals, formal modeling, and field experimentation at large scales according to a planned design will be the most efficient way to proceed in the long run.

LITERATURE CITED

Chilcote, M. W. 2003. Relationship between natural productivity and the frequency of wild fish in mixed spawning populations of wild and hatchery steelhead (*Oncorhynchus mykiss*). Can. J. Fish. Aquat. Sci. 60: 1057–1067.

Dahl, K. 1906. Undersøgelser over nytten av torskeudklækning i øslandske fjorde. Betenkning. Aarsberetning vedkommende Norges Fiskerier for 1906 1: 3–97.

Dannėvig, G. 1963. Artificial propagation of cod. Rep. Norwegian Fish. Mar. Invest. 13: 73–79.

Eberhardt, L. L., and J. M. Thomas. 1991. Designing environmental field studies. Ecol. Monogr. 61: 53–73.

Foerster, R.E. 1936. Sockeye salmon propagation in British Columbia. Bull. No. 53. Biological Board of Canada, Ottawa. As described in Lichatowich, J. 1999. Salmon without rivers—A history of the Pacific salmon crisis. Island Press, Washington, D.C. p. 148.

Foerster, R. E. 1938. An investigation of the relative efficiencies of natural and artificial propagation of sockeye salmon (*Oncorhynchus nerka*) at Cultus Lake, British Columbia. J. Fish. Res. Bd. Can. 4(3):151–161.

Ford, M. J., H. Fuss, J. J. Hard, and E. Lahood. Unpublished ms. Estimating selection gradients in a salmon population using molecular markers. Available from M. J. Ford, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112-2097.

Hilborn, R., and J. Winton. 1993. Learning to enhance salmon production: lessons from the salmonid enhancement program. Can. J. Fish. Aquat. Sci. 50: 2043–2056.

Independent Scientific Advisory Board (ISAB). 2003. Review of salmon and steelhead supplementation. ISAB for the Northwest Power Planning Council, NMFS, and Columbia River Basin Indian Tribes, 851 SW 6th Ave, Suite 1100, Portland, OR 97204. Doc. ISAB 2003-3.

Integrated Hatchery Operations Team (IHOT). 1995. Policies and procedures for Columbia Basin anadromous salmonid hatcheries. Annual Report 1994 to Bonneville Power Administration. BPA Report DOE/BP-60629, Portland, Ore.

Lee, K. N. 1989. Columbia River basin—experimenting with sustainability. Environment 31(6):7–11, 30–33.

Levin, P. S., R. W. Zabel, and J. G. Williams. 2001. The road to extinction is paved with good intentions: Negative association of fish hatcheries with threatened salmon. Proc. Royal Soc. London 268: 1153–1158.

Lichatowich, J. 1999. Salmon without rivers—A history of the Pacific salmon crisis. Island Press, Washington, D.C. p. 128, 215.

Ludwig, D., M. Mangel, and B. Haddad. 2001. Ecology, conservation and public policy. Ann. Rev. Ecol. and System. 32:481–517.

Nickelson, T. 2003. The influence of hatchery coho salmon (*Oncorhynchus kisutch*) on the productivity of wild coho salmon populations in Oregon coastal basins. Can. J. Fish. Aquat. Sci. 60: 1050–1056.

Nickelson, T. E., M. F. Solazzi, and S. L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43: 2443–2449.

Reisenbichler, R. R. In press. Uncertainty and research needs for supplementing wild populations of anadromous Pacific salmon (*Oncorhynchus* spp.). Pages xx-yy in K.M. Leber, H.L. Blankenship, S. Kitada, and T. Svasand [eds] Stock Enhancement and Sea Ranching II. Blackwell Science Ltd.

Salvanes, A. G. V. 2001. Ocean ranching (stock enhancement). In J. Steele, S. Thorpe, and K. Turekian, eds., Encyclopedia of ocean sciences. Academic Press Ltd., New York. Pp. 1973–1982

Smedstad, O. M., A. G. V. Salvanes, J. H. Fosså, and J. T. Nordeide. 1994. Enhancement of cod, *Gadus morhua* L., in Masfjorden: An overview. Aquacult. Fish. Manage. 25: 117–128.

Stewart-Oaten, A., and J. R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. Ecol. Monogr. 71: 305–339.

Stewart-Oaten, A., W. W. Murdoch, and K. Parker. 1986. Environmental impact assessment: “Pseudoreplication” in time? Ecology 67: 929–940.

Tveite, S. 1971. Fluctuations in year-class strength of cod and pollack in southeastern Norwegian coastal waters during 1920–1969. Rep. on Norwegian Fish. Mar. Invest. 16: 65–76.

Ultang, Ø. 1984. The management of cod stocks with special reference to growth and recruitment overfishing and the question whether artificial propagation can help to solve management problems. In E. Dahl, D. S. Danielssen, E. Moksness, and P. Solemdal, eds. The propagation of cod *Gadus morhua* L. Flødevigen Rapportserie 1, p. 795–817.

Walters, C. J. 1986. Adaptive management of renewable resources. McGraw Hill Publishing Co., New York.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conserv. Ecol. 1(2):1. Available online at http://www.consecol.org/vol1/iss2/art1.

Walters, C. J., and R. Hilborn. 1976. Adaptive control of fishing systems. J. Fish. Res. Bd. Can. 33: 145–159.

Walters, C. J., and R. Hilborn. 1978. Ecological optimization and adaptive management. Ann. Rev. Ecol. Syst. 9:157–188.

Walters, C. J., and C. S. Holling. 1990. Large–scale management experiments and learning by doing. 1. Trial and error, 2. Use history, 3. Active adaptive management. Ecology 71:2060–2068.

APPENDIX A

MEETING AGENDA
RECOVERY SCIENCE REVIEW PANEL
NORTHWEST FISHERIES SCIENCE CENTER, SEATTLE WA
JULY 21-23, 2003

July 21: TRT issues for discussion & The role of Panels in Salmon Science

9:00 AM 9:15 AM 10:00 AM	• Arrive at NWFSC • Welcome (Usha Varanasi and Robin Waples • TRT discussion with RSRP: • *Population identification variations for coastal coho* • *ESU criteria* • *The role of hatchery fish in recovery.* • *Other topics*
11:45-1PM	Lunch
1:00 PM	• The role of Panels in Salmon Science & • The ISAB's experience with hatchery issues ISAB members Brian Riddell, Pete Bisson and Eric J. Loudenslager; Jim Lichatowich
Dinner	Barbeque with ISAB and others

July 22: Designing and Implementing Hatchery Experiments

9-11:30AM	• Designing Hatchery Experiments (9-11AM) Steve Katz and Mike Ford
11:30-1:00	Lunch
1-3:00 PM	• Designing and Implementing Hatchery • Update on fitness, straying and Natures research Ken Currens, Rob Jones, Bob Turner, Reg Reisenbichler, Barry Berejikian, Jim Lichatowich
3:00	Panel Meeting Time

July 23:

8:30 AM 10:30	Follow-up discussions on responding to panel recommendations (Bob Lohn and Usha Varanasi) Panel Meeting time, adjourn

APPENDIX B

SUMMARY OF PREVIOUS HATCHERY REVIEWS

The following list of previous work by experts in this field provides a reminder that hatchery issues remain a contentious and nontrivial dimension of salmon recovery. Continued inaction encourages rediscovery of salmon "wheels" and is surely detrimental to recovery goals.

- Flagg, T. A., and C. E. Nash. 1999. A conceptual framework for conservation hatchery strategies for Pacific salmonids. NOAA Technical memorandum NMFS-NWFSC-38.
- Hatchery Scientific Review Group. 2000. Scientific framework for artificial propagation of salmon and steelhead. Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, Wash. Available online November 2003 at http://www.longlivethekings.org/pdf/hsrg_frp_framework_dec_00.pdf.
- Hatchery Scientific Review Group. 2002. Puget Sound and coastal Washington hatchery reform project: A scientific and systematic redesign of hatchery programs to help recover wild salmon and support sustainable fisheries. Hatchery reform recommendations. Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, Wash. February 2002. Available online November 2003 at http://www.longlivethekings.org/pdf/HSRG_Recommendations_Feb_02.pdf.
- Hatchery Scientific Review Group. 2003. Puget Sound and coastal Washington hatchery reform project: A scientific and systematic redesign of hatchery programs to help recover wild salmon and support sustainable fisheries. Hatchery reform recommendations: Skagit River Basin, Nooksack and Samish Rivers, Central Puget Sound. Puget Sound and Coastal Washington Hatchery Reform Project, Seattle, Wash. March 2003. Available online November 2003 at http://www.longlivethekings.org/pdf/HSRG_Recommendations_Mar_03.pdf.
- Hilborn, R., and J. Winton. 1993. Learning to enhance salmon production: Lessons from the salmonid enhancement program. Can. J. Fish. Aquat. Sci. 50: 2043–2056.
- Independent Multidisciplinary Science Team (IMST). 2001. The scientific basis for artificial propagation in the recovery of wild anadromous salmonids in Oregon. Technical Report 2001-1 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board Office, Salem, Ore.
- Independent Multidisciplinary Science Team. 2000. Conservation hatcheries and supplementation strategies for recovery of wild stocks of salmonids: Report of a workshop. Technical Report 2000-1 to the Oregon Plan for Salmon and Watersheds. Oregon Watershed Enhancement Board, Salem, Ore.
- Independent Science Group (ISG). 1996. Return to the river: Restoration of salmonid fishes in the Columbia River ecosystem. Document # 96-6, Northwest Power Planning Council, Independent Scientific Advisory Board, Portland, Ore. Available online November 2003 at http://www.nwcouncil.org/library/1996/96-6/default.htm.

- Independent Scientific Advisory Board for the Northwest Power Planning Council, the National Marine Fisheries Service, and the Columbia River Basin Indian Tribes. 2003. A review of strategies for recovering tributary habitat. ISAB, Portland, Ore. Available online November 2003 at http://www.nwcouncil.org/library/isab/isab2003-2.pdf.
- National Fish Hatchery Review Panel (NFHRP). 1994. Report of the National Fish Hatchery Review Panel. The Conservation Fund, Arlington, Va.
- National Research Council (NRC). 1996. Upstream: Salmon and society in the Pacific Northwest. Report of the Committee on Protection and Management of Pacific Northwest Anadromous Salmonids, Board on Environmental Studies and Toxicology, and Commission on Life Sciences. National Academy Press, Washington, D.C.
- Northwest Fisheries Science Center (NWFSC) Hatchery Program Review. September 18, 2002. NWFSC, 2725 Montlake Blvd. East, Seattle, WA 98112-2097.
- Northwest Power Planning Council (NPPC). 1992. Strategy for salmon. Northwest Power and Conservation Council, 851 S.W. Sixth Avenue, Suite 1100, Portland, OR 97204.
- Waples, R. S. 1999. Dispelling some myths about hatcheries. Fisheries 24: 12–21.
- Waples, R. S., M. J. Ford, and D. Schmitt. 2003. Empirical results from salmon supplementation: A preliminary assessment. In T. M. Bert, ed., Ecological and genetic implications of aquaculture activities. Kluwer Academic Publishers, Dordrecht.
- Wright, S. 1993. Fishery management of wild salmon stocks to prevent extinction. Fisheries 18: 3–4.

APPENDIX C

EXCERPT FROM RSRP REPORT OF DECEMBER 2002

B. Principles Underlying Successful Recovery Actions

The committee recognizes that many recovery actions will be taken by local jurisdictions. Two factors will make recovery difficult to achieve if there is only local decision-making.

(1) Although many important processes occur at the spatial scale of local jurisdictions, many occur at much larger scales, and all processes integrate and interact to determine salmon productivity over larger spatial scales. The effect of local actions on salmon recovery therefore cannot be estimated only locally.

(2) All of these processes occur in temporally and spatially variable environments. The effect of single actions, therefore, cannot be determined outside of a framework that accounts for spatial and temporal variability.

The challenge is how to optimize the process of recovery, given these conditions. The committee believes that the following are prerequisites for success.

1. Recovery actions must be viewed in a specific overall framework of Active Adaptive Management (AAM). Decisions will always be made in an uncertain world; AAM results in comparisons that allow inferences about the causes of differences. Then future management is adjusted to accommodate the new knowledge.

2. AAM requires an explicit experimental framework in which each local decision is a component of a spatially larger design. This requires that each local jurisdiction make decisions in coordination with other jurisdictions in the region.

3. AAM requires that measurements of the effects of actions in different areas are in common units estimated by the same protocols so they can be evaluated in a common framework.

4. Because different processes affecting salmon integrate over large regions, i.e. across the salmon life cycle (point (1) above), there needs to be a common scientifically sound framework for exploring the likely effects of different recovery actions on overall salmon ESU productivity.

5. Points 3 and 4 establish that local decision-making needs to take place in an explicit national/regional scientific framework. It should be the job of regional administrators and scientists to work together to create the overall framework.